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ASSESSMENT OF THE IMPACT OF PROFEBA ON ACID SOIL, AND THE SORGHUM AND MILLET YIELDS UNDER RIDGE AND HOE TILLAGES IN SAHELIENNE ZONE IN MALI

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ABSTRACT

Mali faces a serious threat to its crop production due to increase in soil acidity. Keeping this aspect in mind, soil experiments were conducted at Siguidolo, located in sahelienne zone of Mali. The effect of profeba, ridge tillage, and hoe tillage on soil fertility was determined in addition to millet and sorghum yield. Profeba was applied at optimal levels as control, profeba, profeba + urea, profeba + urea + TPR, or profeba + urea + lime. Profeba was found to have a prospective liming effect, as it elevated pH from 4.78 to 5.33. This effect was augmented to about 5.58 when supplemented with mineral fertilizers and lime. All the different combinations of profeba produced superior millet and sorghum yields, especially with better rainfall. Profeba in combination with urea alone or urea with TPR produced the best grain yield. Compared to hoe tillage, ridge tillage gave a higher millet and sorghum grain yield. The highest VCR, although less than 2, was acquired under profeba + urea for millet and sorghum.

KEYWORDS: Profeba, Acid Soil, Yield, Ridge and Hoe Tillage Mali

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INTRODUCTION

With increasing population, the demand for food is increasing; however, this demand is unable to be met because of the dwindling productive capacities of cropland (Serme, 2016). The economy of Mali is primarily dependent on agriculture, where the rural inhabitants consider land as their prime asset; yet, the land fails to produce sufficient yield to support them economically. In addition, over 80% of the Malian population is directly or indirectly dependent on agriculture.

Mali is known to naturally have soil with low fertility (Jens et al., 2007). In spite this natural situation, most of farmer'sapply lower levels of inorganic and organic fertilizers than what is suggested. The average usage of fertilizer was only 9 kg/ha in 2002 (Jens et al., 2007).These low levels do tend to further weakenthe initial low fertility (Kieft et al., 1994).However, with the increasing population, there is shortage of agriculture land, and this has reduced the fallow period of the land, further deteriorating the situation (Hoefsloot et al., 1993).

The foremost problem in agriculture soils is its acidity, along with its sandy texture, low water holding capacity as well as low carbon content. Soil nutrient depletion nowadays causes serious setbacks to crop yield and food security (Doumbia*et al*., 2009).Soil acidity has a complex physiological role, as it results in the deficiency of

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certain nutrients (P, Ca, and Mg), while simultaneously manifesting the presence of certain phytotoxic nutrients (Al and Mn),which reduce crop growth and yield (Zhuo*et al.,* 2009a).

In Mali, by 1952, 4% of the agriculture land had been rendered infertile, and it rose to 26% by 1975. The mineral content lost was estimated in the 1990s, and it was found to be 10-60% (Kieft et al., 1994). The mineral content was further elaborated as individual entities by Stoorvogel et al. (1990) and Van der Pol (1992),who showed that Mali had lost 8 kg/ha of Nitrogen (N), 2 kg/ha of phosphorus (P_2O_5), and 8 kg/ha of potassium (K_2O)from its soils during the cropping season of 1993. They also anticipated further loss by the year 2000 as 11, 6, and 12 kg/ha, respectively.

This alarming situation has triggered the scientific community to find remedies. Some of the remedies include ridge tillage with water harvesting, soil erosion prevention and control, and producing germplasm for agroecology (Gigou et al., 2006 and Doumbia et al., 2009). However, these remedies have failed to make a mark and efforts for a reliable solution continue. The most efficient remedy requires the usage of easily available and affordable liming compounds. It requires eradicating aluminium and iron toxicity, and simultaneously making available P, as well as calcium and nitrogen (Adams, 1984 and Black, 1993). This is done by supplementing with inorganic fertilizers such as Tilemsi Phosphate Rock (TPR) (Julio, 1999). Organic manures have also been reported to improve the pH levels of acid soils.

MATERIALS AND METHODS

Study Site

Siguidolo, in Mali, is located between 6^o 44’ 54” and 6^o 46’ 12” W and 12^o 54’ 00” and 12^o 56’ 24” N. This experiment was performed in this region, as the soils here are chiefly sandy loam. Rainfall range from 600-800mm. Siguidolo is characterised by lateritic highlands alternating with moderate slopes and plains. Geographically, the vegetation is savanna bushlands (Kablan, 2008). The flora is predominated with sparse Shea butter trees (*Vitellariaparadoxa, Gaertn*), Baobab (*Adansoniadigitata, L.*) and Nere (*Parkiabiglobosa*) at the bottom of toposequence; *Guierasenegalensis*, *Combretumgasalense* and *Combretummicranthum*formed the shrubby foliage at the middle topo sequence, with *Pennisetumpedicelatum* and *Pennisetumpurpureum*as the grasses in the bottom of the toposequence (Traore, 2003).

Profeba

Profebais the brand name of the enriched organic compost manufactured and marketed by the agribusiness company ‘Toguna’. This fertilizer is popular among the farmers of West Africa. Table 1 presents the chemical composition of Profeba.

Table 1: Chemical Profile of Profeba

Nutrients	Nutrient Content
Dry matter (kg)	51.00
Total N (%)	1.73
Total P (%)	0.40
Total K (%)	1.05
Carbon (%)	47.73
C/N	27.59
Calcium (%)	0.04
Magnesium (%)	0.29
Fe (mg kg^{-1})	120.47
Zn (mg kg^{-1})	46.90
Cu (mg kg^{-1})	2.44

Study Outline

The experiments were outlined to be performed with millet (*Pennisetumglaucum*) and sorghum (Sorghum *bicolor L. Moench*). Each field study was a factorial test that helped to investigate two types of tillage applications (Ridge tillage and hoe tillage) and five types of soil supplementations (P_0 = No supplementation; P_1 = Profeba; P_2 = Profeba + Urea; P_3 = Profeba + Urea + TRP [Tilemsi Phosphate Rock] and P_4 = Profeba+ Urea + Lime). The study was designed as a randomized complete block, with three replicates. The type of tillage constituted the key plot, whereas soil supplementation was the subplot. The subplots measured 4 x 5m. There was 1m wide access space between any two key plots. Table 2 illustrates the quantity of soil supplement used.

Table 2: Modifications in the Millet and Sorghum Field Soil

Soil Amendment	Profeba Mg Ha^{-1}	Urea Kg Ha^{-1}	TRP Kg Ha^{-1}	Lime Kg Ha^{-1}
Control (No amendment)	0	0	0	0
Profeba	5	0	0	0
Profeba + Urea	5	50	0	0
Profeba + Urea + RP	5	50	100	0
Porfeba + Urea+ Lime	5	50	0	750

N.B. Urea was applied to sorghum at the rate of 100 kg ha^{-1}; Mg = Mega grams

Preparation of Soil and Planting

The ridged plots were planted by seeding using tine harrows. A mould board plough was used for this purpose and it was drawn by an animal. Hoe tillage was used to plant the remainder plots. Improved plant strains were used in the study. Toronio millet was used for planting, whereas for sorghum, it was CSM63E, which is commonly referred to as Jakumbe. The assess space between millet and sorghum crops was 50 x 70 cm.

Managing the Cultivation and Yield

Every 15 days and 30 days subsequent to planting, weeding was done. Thereafter, after the completion of 40 days, ploughing was done. Mould board ploughs, which were animal drawn, or tine harrows were used for this purpose. The grain yield was gathered from the three central rows and quantified. The yield was determined using samples of stem, grain, and leaves.

Soil Supplementation

Profeba was applied as the chief soil supplement, followed by Tilemsi Phosphate Rock (TPR), which was obtained from the commercial society of SeydouNantoume and lime. Profeba, TPR, and lime were used after weighing. The supplement was distributed throughout the field and combined with the soil prior to planting. Nitrogen was chiefly available to the crops in the form of urea. It was added to the soil every 15 days and 30 days subsequent to planting.

Laboratory Assessment of the Soil Samples

The soil from the study fields was collected in polythene bags prior to planting and subsequent to harvest. Each sample constituted the soil obtained from three areas from a depth of 0 cm to 20 cm. These soil samples were subjected to physical and chemical analyses. Profeba content in the soil was ascertained at the soil water and plant laboratory of Institute of Rural Economy of Mali. In addition, the following soil features were evaluated:

Texture of Soil

The hydrometer method (Anderson and Ingram, 1993) was employed to determine the size of the soil particles. In this method, 50 g of air-dried soil was measured and placed in a conical flask. Into this, sodium hexamegaphosphate was added, which is a dissolving agent. This mixture was placed on a reciprocal shaker at 400 r.p.m for 18 hours. Later, these samples were transferred to sedimentation cylinders. Using distilled water, the samples were made up to 1000 mL. Thereafter, a hydrometer determined the density of the suspension of soil and water at 40 seconds and 3 hours. The temperature at each reading was assessed with a thermometer. Ultimately, the composition of sand, clay and silt in the soil as percentages was estimated with the following formulas, respectively:

$$\text{Percentage of sand in the soil} = 100 - \{H_1 - 0.2 \text{ x } (T_1 - 20) - 2.0\} \text{ x } 2;$$

$$\text{Precentage of clay in the soil} = \{H_2 + 0.2 \text{ x } (T_2 - 20) - 2.0\} \text{x } 2;$$

$$\text{Percentage of silt in the soil} = 100 - (\%\ \text{Sand} + \%\ \text{Clay}).$$

where,

H_1= first reading of hydrometer,

H_2=second reading of hydrometer,

T_1= temperature of suspension at first reading of hydrometer, and

T_2= temperature of suspension at second reading of hydrometer.

pH of the Soil

The McLean (1982) method was employed to determine the pH of the soil. The soil (10 g) was collected in a 50 mL beaker and mixed with 10 mL of distilled water. This mixture was stirred for five minutes. The mixture was allowed to stand for 30 minutes. Thereafter, a pH meter (Eutech Instruments pH 510) determined the pH of the soil. The instrument was zeroed by placing its glass electrode in distilled water. The readings were obtained by maintain the sample temperature at 26.9°C.

Organic Carbon Content of Soil

The modified Walkley-Black wet oxidation method according to Nelson and Sommers (1982) was employed to determine the organic carbon content of soil. Soil (2.00 g) sample was collected and placed in a 500 mL conical flask. To this, 10 mL of 0.166 M (1.0 N) $K_2Cr_2O_7$ solution was poured, followed by 20 mL of concentrated H_2SO_4. The mixture was cooled on an asbestos sheet for 30 minutes. Thereafter, distilled water (200 ml) was added, in addition to 10 mL of H_3PO_4 and 1.0 mL of diphenylamine solution, as an indicator. The mixture obtained was titrated against 1.0 M ferrous sulphate solution. The titration continued until the blue-black colour changed to a permanent green. A blank was maintained without soil for every batch, and this too was titrated in a similar manner.

The soil organic carbon was further calculated by the following formula:

$$\%C = \frac{N \text{ x } (V_{bi} - Vs) \text{ x } 0.003 \text{ x } 1.33 \text{ x } 100}{g}.$$

Where,

N =Normality of $FeSO_4$ solution;

V_{bl} = Volume of $FeSO_4$ solution used for blank titration in mL;

V_s = Volume of $FeSO_4$ solution used for sample titration in mL;

g = mass of soil used in grams;

0.003= milli-equivalent weight of C in grams (12/4000);

1.33 = correction factor. It converted the Wet combustion C value to the true C value as the Wet combustion method was about 75 % efficient in estimating C value (i.e. 100/75 = 1.33).

Total Nitrogen Content of Soil

Kjeldahl digestion method (Bremner and Mulvaney, 1982) was employed to determine the total nitrogen content of soil. Soil sample (10 g) was placed in a 250 mL Kjeldahl digestion flask. To this, 10 mL of distilled water was added. Subsequently, concentrated H_2SO_4 (10 ml), one tablet of selenium and potassium sulphate mixture, and salicylic acid (0.10 g) were added. This mixture was left to stand for 30 minutes. Later, the flask was heated at very low temperatures to enable the conversion of any nitrate or nitrites in the mixture into ammonium compounds. Steadily, the temperature was raised (300 to 350 $^{o\,C}$) so that the soil was digested to a permanent clear color. Thereafter, the digest was cooled. The digest was now transferred to a 100 mL volumetric flask. The volume was made up to the mark with distilled water. From this aliquot, 20 ml was transferred to a tecatar apparatus. On distillation, ammonium was collected into a solution having 10 mL boric acid. Bromocerol green and methyl red were added as the indicators. The distillate was titrated against 0.01 M HCl. A blank, without any soil, was used for every batch. The blank helped to assess any traces of nitrogen in the reagents or the water used.

Consequently, the total nitrogen content of the soils was estimated by the following formula:

$$\%\ \mathrm{N} = \frac{(\mathrm{a} - \mathrm{b})\ \mathrm{x}\ 1.4\ \mathrm{x}\ \mathrm{M}\ \mathrm{x}\ \mathrm{V}}{\mathrm{sxt}}$$

Where,

a = HCl used for sample titration in mL,

b = HCl used for blank titration in mL,

M = molarity of HCl,

V = total volume of the digest,

s = weight of soil taken for digestion in grams,

t = volume of aliquot taken for distillation,

1.4 = 14 x 10^{-3} x 100 % (14 is the atomic weight of N).

Available Phosphorus Content in the Soil

The Bray P1 method (Bray and Kurtz, 1945) was employed to determine the available phosphorus content of soil. Soil sample (2 g) was extracted using 20 ml of Bray P1 solution (0.03 M NH4F and 0.025 M HCl). As soon as Bray P1 solution was added to the soil sample, the mixture was placed on a Stuart reciprocal shaker for 1 minute. Immediately, the mixture filtered using a Whatman no. 42 filter paper. A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6.0 was set up by pipetting l 0, 10, 20, 30, 40, 50 ml of 12 mg Pl^{-1}, respectively into a 100 ml volumetric flask. The test series were made up to the mark with distilled water. The quantity of phosphorus in the sample was estimated by a pye-unicam spectrophotometer. The readings were obtained at a wavelength of 660 nm using the blue ammonium molybdate method. Ascorbic acid was the reducing agent.

The available phosphorus content of the soil was estimated with the following formula:

$$P(\mathrm{mg\ kg^{-1}}) = \frac{(a - b) \text{ x Vs x df}}{g}$$

Where,

a = Bray P1 solution in sample extract in mg;

b = Bray P1 solution in blank in mg;

df = dilution factor;

Vs = the volume of extract;

g = weight of sample in grams.

Available potassium content of the soil

Sparks et al. method (1996) was employed to estimate the available potassium content of the soil. Initially, the soil was extracted using 0.1M HCl. Oxalic acid may also be employed for extraction purposes This extraction helps to approximate the potassium content in soil in the soluble form and in the complex form, in addition to indicate roughly the absorbent quantity of the minerals. Increased usage of HCl could extract more soil potassium. This phenomenon is explained by the rapid destruction of minerals because of the higher acidity. Oxalic acid extraction maintains the H+ ion concentration as constant and dissolves the calcium in the CaCO3 precipitates forming calcium oxalate.

The available potassium content in the soil was estimated using the following formula:

Potassium in 100 $g^{-1}$of soil (in mg) = (a-b);

Dipotassium oxide in 100 $g^{-1}$of soil (in mg) = 1.2 (a-b).

Where,

a = potassium amount in ppmin sample,

b= potassium amount in ppm in blank.

Grain yield was determined by the harvest from the center of each treatment plot. The harvest yield from the center of each plot was estimated as 4.29 m^2, and this yield was dried. The yield from the border rows in the treatment

plots were not used for the calculations. The weight of the dried, harvested grains was measured for each hectare in the center treatment plots.

Statistical Analysisof the Data

The study data were analysed statistically using the GenStat statistical package (9th Edition).

Effectiveness of Land Management Practices

In order to determine the effectiveness of the various soil management interventions, VCR was calculated. VCR was used as the first indication that the investment was accepted. It was calculated with the help of the unsubsidized input costs and the mean prices of the crop.The following formula of Nziguheba et al. (2010) was used to calculate VCR.

$$\mathrm{VCR} = \frac{\mathrm{Y} - \mathrm{Yc}}{\mathrm{x}}$$

where,

Y= Cost of yield from the treatment plot,

Y_c = Cost of yield from the control plot,

X = Cost of inputs (seeds and fertilizers).

RESULTS

Initial Physicochemical Properties of the Soil before Initiation of the Field Studies

Prior to field studies, the physicochemical properties of the soil were ascertained. On the basis of these tests, the soil was classified as sandy loam (Table 3). This was the chief soil type predominantly prevalent in about 78% of the study area. Sandy loam soils have acidic pH; therefore, addition of lime to these soils is mandatory during crop cultivation. In addition, sandy loam soils have decreased levels of organic carbon in comparison to other soils. Overall, the nutrient content in sandy loam soils is very poor. Hence, such soils must be amended with mineral/organic fertilizers to improve its nutrient content.

Table 3: Preliminary Physicochemical Properties of the Trial Fields

Soil Parameters	Level
pH(1:1, H_2O)	4.78
Organic Carbon (%)	0.45
Total N (%)	0.02
Available P (mg kg^{-1})	2.04
Exchangeable K ($cmol_c kg^{-1}$)	0.10
Exchangeable Ca ($cmol_c kg^{-1}$)	1.54
Exchangeable Mg ($cmol_c kg^{-1}$)	0.81
Exchangeable Na ($cmol_c kg^{-1}$)	0.06
ECEC ($cmol_c kg^{-1}$)	2.57
Sand (%)	77.02
Silt (%)	19.34
Clay (%)	3.63

Influence of Tillage and Soil Amendments on Certain Soil Chemical Parameters

Effect of Type of Tillage Employed and Soil Supplementation on pH

The field study was conducted in two cropping seasons. During the cropping season of 2013 (Table 4), the type of tillage employed affected the soil pH ($p<0.05$) for sorghum cultivation. Ridge tillage was observed to improve soil pH.

However, during the same cropping season, supplements added to the soil did not have a significant ($p>0.05$) outcome with regard to soil pH. Such a consequence was noticed for both sorghum and millet cultivation. In the cropping season of 2014 produced varied results. Soil amendments improved significantly the soil pH levels ($p<0.05$). This improvement was reported for millet crops as well as sorghum crops.

Different amendments had varied impact on the soil pH level. For millet cultivation, pH ranged between 4.80 and 5.56. The pH levels of soil reduced with amendments in the following order: $P_4 > P_3 > P_2 > P_1 > P_0$.Not much significant variation in pH levels was reported among P_4, P_3 and P_2, which had higher values than P_1 and P_0. P_0 had the least pH ($P<0.05$). For sorghum cultivation, similar outcomes were recorded. The pH of soil for sorghum cultivation ranged from 4.36 to 5.58. Therefore, it could be concluded that for millet cultivation in 2013, both soil supplementation and type of tillage employed influenced pH ($P<0.05$).

Table 4: Modifications in Soil pH by the Influence of Tillage and Soil Amendments

Soil Amendment	pH(1:1, H_2O)			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	4.93	4.83	4.80	4.36
P_1	4.87	4.90	5.33	5.20
P_2	5.07	5.00	5.48	5.53
P_3	5.02	5.03	5.54	5.45
P_4	4.92	4.95	5.56	5.58
Fpr. (soil amendment)	0.68	0.92	<.001	<.001
Lsd (0.05)	0.32	0.50	0.20	0.29
Tillage practices	1.1.11	1.1.12	1.1.13	1.1.14
R_1	4.96	5.05	5.44	5.33
R_2	4.96	4.76	5.24	5.15
Fpr. (Tillage practice)	0.98	0.01	0.16	0.15
Lsd (0.05)	0.27	0.45	0.32	0.26
Fpr. (soil amendment x Tillage)	0.02	0.13	0.14	0.13
CV%	5.3	8.3	3.1	4.6

N.B. TPR = Tilemsi Phosphate Rock

Table 5: Mean Values of the Interaction between Tillage and Amendments to Influence Soil pH under Millet Cultivation (2013)

Soil Amendment	Tillage	
	R_1	R_2
P_0	4.77	5.09
P_1	5.01	4.73
P_2	5.09	5.04
P_3	5.26	4.78
P_4	4.67	5.17
Lsd(0.05)	0.4504	
CV (%)	5.3	

R_1 = Ridge tillage, R_2 = Hoe tillage

Table 5 illustrates the means obtained by the interaction between the type of tillage used and the supplements added to the soil. The P_3 x R_1 interaction produced the highest pHvalue in the study. P_4 x R_1 interaction resulted in the lowest pH. The impact because of soil supplementation was not significant. Soil supplement P_3 on interacting with R_1 tillage type could significantly ($P<0.05$) improve the pH, when compared to P_0 x R_1 and P_4 x R_1 interactions. The impact on soil pH because of the type of tillage was not significant. However, on employing soil supplements along with the tillage practice, the effect was more significant ($P<0.05$). P_4 x R_2 and P_3 x R_1 interactions resulted in improved pH than P_4 x R_1 and P_3 x R_2, respectively. Therefore, the outcome on pH levels of soil is not by the separate impact of soil supplements or tillage type, but by their interaction, as both influence each other.

Effect of Type of Tillage Employed and Soil Supplementation on Soil Organic Carbon Content

During the cropping seasons of 2013 and 2014, no significant ($p>0.05$) influence was noticed by the type of tillage employed on soil organic carbon content. Ridge tillage showed slightly improved soil organic carbon content. This outcome was similar for both millet and sorghum cultivation (Table 6).

During the cropping season of 2013, soil supplementation did not significantly influence soil organic carbon content. However, during the cropping season of 2014, soil supplementation had a significant impact ($p<0.05$).

During the millet cropping season of 2014, soil organic carbon content ranged between 0.37 and 0.54. Significant difference in levels was noticed between P_0 and P_1 and P_2, and P_3 and P_4. In 2014, for sorghum cultivation, soil organic carbon content varied significantly between $P_0$and all the other soil supplements, as well as between P_3 and P_2. The soil organic carbon content ranged between 0.33 and 0.53. The increase in soil organic carbon content because of soil supplementation was in the following order: $P_4> P_3> P_1> P_2> P_0$. However, the interaction between soil supplements and tillage did not significantly improve the soil organic carbon content levels.

Table 6: Modifications in Soil Organic Carbon by the Influence of Tillage and Soil Amendments

Soil Amendment	Carbon (%)			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	0.38	0.32	0.37	0.33
P_1	0.32	0.39	0.50	0.49
P_2	0.37	0.41	0.53	0.48
P_3	0.37	0.31	0.54	0.51
P_4	0.36	0.35	0.54	0.53
Fpr. (soil amendment)	0.38	0.17	0.003	<.001
Lsd (0.05)	0.06	0.09	0.03	0.05
Tillage practices	1.1.15	1.1.16	1.1.17	1.1.18
R_1	0.36	0.38	0.52	0.49
R_2	0.35	0.33	0.51	0.45
Fpr. (Tillage practice)	0.73	0.11	0.44	0.14
Lsd (0.05)	0.07	0.06	0.03	0.06
Fpr. (soil amendment x Tillage)	0.32	0.87	0.69	0.28
CV%	14.4	21.6	6.2	7.7

Modifications in Soil Nitrogen, Phosphorus and Potassium by the Influence of Tillage and Soil Amendments

During sorghum cultivation in 2013, soil nitrogen was found to be significantly ($p<0.05$) influenced by the type of tillage practices employed (Table 7). However, such aninfluence was not observed for millet cultivation. The next year in

2014 the observations were reversed, with tillage having no significant influence for sorghum cultivation but making a significant difference for millet cultivation. The only consistent finding was that ridge tillage improved soil nitrogen for both millet and sorghum cultivation, and this finding was similar in 2013 and 2014.

Soil amendments too influenced total soil nitrogen. In 2013, under millet cultivation, soil amendments improved total soil nitrogen and the effect was significant ($p<0.05$). However, it was not so for sorghum cultivation (not significant; $p>0.05$). These findings were not similar in 2014, when both sorghum and millet cultivated fields reported a significant ($p<0.05$) influence on the soil nitrogen after the soil was amended. However, the effect was very low, with values ranging from 0.01 to 0.03.

These findings helped to conclude that in both the years, 2013 and 2014, there was no significant impact by the type of tillage used on the soil amendments in both millet and sorghum cultivation.

Table 7: Modifications in Total Nitrogen Content by the Influence of Soil Amendments

Soil Amendment	Total Nitrogen (%)			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	0.01	0.03	0.01	0.01
P_1	0.01	0.03	0.01	0.02
P_2	0.02	0.03	0.02	0.03
P_3	0.02	0.03	0.02	0.02
P_4	0.02	0.03	0.02	0.03
Fpr. (soil amendment)	0.02	1.00	0.01	<.001
Lsd (0.05)	0.007	0.013	0.0071	0.009
Tillage practices	1.1.19	1.1.20	1.1.21	1.1.22
R_1	0.01	0.03	0.019	0.02
R_2	0.01	0.02	0.016	0.02
Fpr. (Tillage practice)	0.37	0.01	0.06	0.25
Lsd (0.05)	0.012	0.010	0.003	0.004
Fpr. (soil amendment x Tillage)	0.34	0.44	0.90	0.98
CV%	39.5	35.6	33.1	29.8

Table 8 illustrates the impact of soil supplements on available phosphorus content in soil. During the cropping season of 2013, the type of tillage employed did not significantly ($p>0.05$) influence soil phosphorus content for millet crops, whereas significant ($p<0.05$) influence was noticed for sorghum crops. During the cropping season of 2014, the influence was reversed, with the type of tillage employed significantly impacting the soil phosphorus content for millet cultivation and not for sorghum cultivation. Ridge tillage increased the available phosphorus content of soil during both the cropping seasons for both the crops.

During the cropping seasons of 2013 and 2014, soil supplements improved significantly ($p>0.05$) the soil phosphorus content for both millet and sorghum cultivation.

In the cropping season of 2013 for millet cultivation, the available phosphorus content of the soil was in the range of 1.20 to 1.91 mg kg^{-1}. On utilizing soil supplements, the phosphorus level in the soil was in the following order: $P_4> P_1> P_2 =P_3> P_0$ (Table 8). Only P_0 amendment resulted in significantly ($P<0.05$) lesser available phosphorus content, which did not vary ($P<0.05$) for the other amendments. The influence of soil supplements on phosphorus content during sorghum cultivation was in the following order: $P_1> P_0> P_4> P_2> P_3$; of the phosphorus content ranged from 1.04 to 2.16 mg kg^{-1}. The latter three soil supplements did not significantly differ in the outcomes, and showed lower available phosphorus

content ($P<0.05$) than P_1 and P_0, which significantly differed between themselves. P_1 amendment showed maximum increase in the phosphorus content, whereas P_2 amendment showed the least increase in phosphorus content.

In the cropping season of 2014, the varied soil supplements produced significant varied impact on soil phosphorus content. Phosphorus content of the soil for millet cultivation ranged between 1.39 and 2.47 mg kg^{-1}. The effect of the soil supplements was in a declining order as follows: $P_3>P_4>P_1>P_2>P_0$. No significant difference in phosphorus levels was reported between P_3 and P_4 and between P_1 and P_2. The first two soil supplements produced significantly elevated phosphorus content. P_0 amendment resulted the least available phosphorus content. For sorghum cultivation, the cropping season of 2014 recorded improved phosphorus content when compared to 2013; for the cropping season of 2014, from the phosphorus content was in the 1.65 to 4.01 mg kg-1 range. The effect of the soil supplements for sorghum cultivation was in a declining order as follows: $P_3>P_4>P_2>P_1>P_0$. All the various supplements produced results that significantly varied from each other ($P<0.05$).

Table 8: Modifications in the Availability of Phosphorus by the Influence of Soil Amendments

Soil Amendments	Available Phosphorus mg kg^{-1}			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	1.20	1.25	1.39	1.65
P_1	1.56	2.16	2.08	2.45
P_2	1.50	1.21	2.45	3.24
P_3	1.50	1.04	2.47	4.01
P_4	1.91	1.22	2.45	3.53
Fpr. (soil amendment)	0.04	<.001	<.001	<.001
Lsd (0.05)	0.42	0.27	0.24	0.47
Tillage practices	1.1.23	1.1.24	1.1.25	1.1.26
R_1	1.56	1.24	2.06	3.27
R_2	0.10	1.11	1.88	2.69
Fpr(Tillage practice)	0.78	0.04	0.051	0.11
Lsd (0.05)	0.89	0.11	0.02	0.80
Fpr(soil amendment x Tillage)	0.77	0.51	0.67	0.04
CV%	22.6	18.9	10.3	13.0

Table 9: Mean Values of the Interaction between Tillage and Amendments for Available P under Sorghum Cultivation (2014)

Soil Amendment	Tillage	
	R_1	R_2
	mg kg^{-1}	
P_0	1.59	1.72
P_1	2.16	2.75
P_2	3.28	3.21
P_3	3.44	4.59
P_4	2.98	4.08
Lsd (0.05)	0.8774	
CV (%)	8.3	

R_1 = Ridge tillage, R_2 = Hoe tillage

During the sorghum cultivation season of 2014, the interaction between the type of tillage employed and soil supplementation had a significant ($P<0.05$) effect on the available phosphorus content of soil. The mean values of this interaction are illustrated in Table 9. P_2 x R_1 and P_3 x R_1 interactions produced significantly ($P<0.05$) elevated available phosphorus content when compared with the other interactions with the same tillage practice, which had no significant

difference. P_3 x R_2 and P_4 x R_2 interactions produced significantly elevated phosphorus content when compared with the other interactions employing this tillage practice. P_0 x R_2 interaction produced the least available phosphorus content in soil.

Table 10 illustrates the mean of the available exchangeable potassium content in the soil when subjected to varied soil supplements and tillage practices. During the cropping season of 2013, the type of tillage employed did not have a significant ($p>0.05$) impact on the potassium levels of the soil for the millet crops; however, the impact was altered for sorghum crops, which invariably had a significant ($p>0.05$) impact. During the cropping season of 2014, the type of tillage used for both millet and sorghum cultivation did not produce any significant ($p<0.05$) effect to raise the potassium levels of soil. In comparison to all the tillage types, ridge tillage was responsible for elevating the potassium levels of soil during millet and sorghum cultivation in both the cropping seasons.

Soil supplementations did not significantly improve the soil potassium levels. This observation was similar for both millet and sorghum cultivation in both the cropping seasons. However, P_3 amendments comparatively improved potassium levels in millet during the cropping season of 2013 and in sorghum during the cropping season of 2014.

Table 10: Modifications in Exchangeable Potassium Content by the Influence of Soil Amendments

Soil Amendment	Exchangeable Potassiumcmol$_c$ kg^{-1}			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	0.16	0.10	0.04	0.021
P_1	0.16	0.13	0.05	0.023
P_2	0.17	0.13	0.05	0.021
P_3	0.182	0.15	0.05	0.026
P_4	0.180	0.13	0.04	0.025
Fpr. (soil amendment)	0.96	0.39	0.45	0.76
Lsd (0.05)	0.07	0.04	0.011	0.009
Tillage practices	1.1.27	1.1.28	1.1.29	1.1.30
R_1	0.18	0.14	0.05	0.026
R_2	0.15	0.11	0.04	0.020
Fpr. (Tillage practice)	0.29	0.04	0.13	0.18
Lsd (0.05)	0.04	0.02	0.007	0.010
Fpr. (soil amendment x Tillage)	0.43	0.60	0.45	0.76
CV%	38.3	30.5	20.6	33.0

Effect of Tillage and Soil Amendments on Yields

Impact on Millet and Sorghum Grain Yield by Type of Tillage Employed and Soil Supplements Used

Table 11 illustrates the effect on crop yield by the type of tillage employed and the soil supplements used. The type of tillage used had a significant impact ($P<0.05$) on the millet grain yield in both the cropping seasons; however, it was not so for sorghum. In comparison to all the tillage types, ridge tillage produced a higher grain yield for both the crops.

Contrariwise, adding supplements to the soil could significantly ($P<0.05$) influence the crop yield of both crops for both the cropping seasons.

During the cropping season of 2013, the grain yield for millet ranged between 311 and 1321 kg ha^{-1}. On amending the soil with supplements, the decreasing trend in grain yield was in the following order: $P_4> P_2> P_3> P_1> P_0$. All

amendments produced significant (P<0.05) difference in yield; only P_2 and P_3 amendments did not show any significant difference in yield. During the cropping season of 2014, the grain yield for millet ranged between 384 and 1251 kg ha^{-1}. On amending the soil with supplements, the decreasing trend in grain yield was in the following order: $P_3 > P_2 > P_4 > P_1 > P_0$. P_3, P_2 and P_4 amendments did not report any significant difference in their yield; however, the produce was significantly (P<0.05) greater than P_1 and P_0 amendments, which reported significant differences in grain yield.

During the cropping season of 2013, the grain yield for sorghum ranged between 55 and 375 kg ha^{-1}. On amending the soil with supplements, the decreasing trend in grain yield was in the following order: $P_2 > P_1 > P_4 > P_3 > P_0$. All amendments produced significant difference in yield; only the difference between P_2 and P_1 and P_4 and P_3 amendments were not significant.

During the cropping season of 2014, the grain yield for sorghum was greater when compared with 2013. The grain yield ranged between 101 and 1309 kg ha^{-1}. On amending the soil with supplements, the increasing trend in grain yield was in the following order: $P_0 < P_1 < P_3 < P_2 < P_4$. All amendments produced significant difference in yield; only the differences of P_2 and P_4 were not significant. Both sorghum and millet produced contradictory and inconsistent data in both the cropping seasons.

In all of the experiments, the control crop produced the least grain yield. No single parameter could be determined as the cause for resulting in high grain yield, as no consistent data was obtained**.**

Table 11: Sorghum and Millet Yield Depending on the Tillage and Soil Amendments

Soil Amendment	Grain Yield kg ha^{-1}			
	2013		2014	
	Millet	Sorghum	Millet	Sorghum
P_0	311	55	384	101
P_1	660	372	1014	1036
P_2	932	375	1235	1261
P_3	894	199	1251	1222
P_4	1321	206	1223	1309
Fpr. (soil amendment)	<001	<001	<001	<001
Lsd (0.05)	281.7	99.1	88.8	84.5
Tillage practices	1.1.31	1.1.32	1.1.33	1.1.34
R_1	870	281	1056	1011
R_2	777	202	986	960
Fpr. (Tillage practice)	0.63	0.006	0.01	0.07
Lsd (0.05)	723	25.7	42	58.8
Fpr. (soil amendments x Tillage)	0.11	0.04	0.13	0.46
CV%	27.9	33.5	7.1	7.0

Table 12: Mean Values of the Interaction between Tillage and Amendments on Sorghum Cultivation (2013)

Soil Amendments	Tillage	
	R_1	R_2
	kg ha^{-1}	
P_0	58	52
P_1	415	329
P_2	509	241
P_3	239	160
P_4	186	227
Lsd(0.05)	131.6	
CV (%)	33.5	

R_1= Ridge tillage; R_2= Hoe tillage

Table 12 illustrates the mean values of the interaction obtained as a result of interaction between the type of tillage employed and on the supplements added to the soil during sorghum cultivation in the cropping season of 2013. Soil amendment P_2 produced the highest grain yield at 509 kg ha^{-1}, followed by P_1, producing 329 kg ha^{-1}. Tillage types, R_1 and R_2, produced the next highest crop yield, respectively. On studying the interaction between the type of tillage employed and the soil supplements used, P_0 x R_1 produced the lowest positive yield; however, P_2 x R_1 produced the highest yield. P_1 x R_1 and P_2 x R_1 interactions did not report any significance. The interactions reported the lowest grain yield for P_0 x $R_{2,}$ and the highest grain yield for P_1 x R_2.

The Impact on Sorghum Value Cost Ratio by the Tillage Method Practiced and Soil Amendments Employed

Table 13 shows the VCR under sorghum. According to performance, the VCR under ridge tillage was placed hierarchically as Profeba + Urea + TPR>Profeba + Urea>Profeba>Profeba + urea + lime; similarly, for hoe tillage, the ranking was Profeba + urea>Profeba>Profeba + urea+ TPR>Profeba + urea + lime. For both ridge and hoe tillage, Profeba + urea produced the best VCR. VCR was the least under hoe tillage whenProfeba + Urea + Lime was applied.

Table 13: VCR under Sorghum Cultivation in 2014

Tillage	Soil Amendments	Grain Yield kg ha^{-1})	Income from Grain (CFA)	Cost of Amendments (CFA)	VCR
RT	Control	110.63	-	-	-
RT	Profeba	1044.3	163388.8	152500	1.07
RT	Profeba+ urea	1290.83	206531.5	170000	1.21
RT	Profeba+urea+TPR	1293.86	207061.8	175000	1.18
RT	Profeba+urea+lime	1317.63	211221.5	560000	0.37
HT	Control	90.74	-	-	1.1.35
HT	Profeba	1026.88	163824.5	152500	1.07
HT	Profeba+ urea	1232.16	199748.5	170000	1.17
HT	Profeba+urea+TPR	1149.96	185363.5	175000	1.05
HT	Profeba+urea+lime	1301.08	211809.5	560000	0.37

DISCUSSIONS

Changes in the Soil Chemical Characteristics by the Type of Tillage Employed and Soil Alterations Used

The Influence on Soil pH and Organic Carbon Content by the Type of Tillage Employed and Soil Alterations Used

The study site, Mali, has strong acidic soils. Such soils make it difficult for the plant to absorb the required nutrition to attain a good yield. In acidic soils, the phosphate ions in the soil combine with iron and aluminium ions forming compounds that are in an unabsorbable state for the plants. Increasing the soil pH above 5.5 can undo the harmful effects of acidity.

During the cropping season of 2013, the type of tillage employed altered soil pH in extremely lesser levels. Among the tillage types used, ridge tillage had a significant impact, and this was observed for sorghum cultivation. During the cropping season of 2014, the type of tillage employed had a significant impact ($P<0.05$). The pH of the soil improved from 4.78, with an increase of 10-12% and 7.2-8.8%, respectively for ridge and hoe tillages. Adding supplements to the soil improved soil pH. The impact was noticed more specifically in 2014. P4 amendments could produce the best pH levels at 5.56 and 5.58, respectively for millet and sorghum cultivation, which is an increase of 13.3 and 14.3%, respectively.

The percentage of increase was 10% and 8%, respectively when only Profeba was used as the supplement. The reason for the increase in soil pH with TPR when compared to lime could be influenced by the period of lime application. Generally, lime supplements should be added at least prior to 6 months of planting to produce a significant impact. However, lime was applied just before planting in the study, and so could not influence soil pH. For millet crops, during the cropping season of 2013, P_3 x R_1 and P_2 x R_2 interactions improved soil pH by 9% and 5% under ridge and hoe tillage, respectively from an initial pH of4.78.

Acidic soils were also noted to have a low soil organic carbon content. Reduced carbon content is also responsible for the poor yield. According to LSEP (2008), soil supplements that can improve the carbon content by 2.3 % can improve crop yield. During the cropping season of 2013, both the tillage types could not improve soil organic carbon content. However, during the cropping season of 2014, the soil carbon content improved by 18 - 23% and 1-11%, respectively by ridge tillage and 11.1% and 21.6%, respectively by hoe tillage for sorghum and millet crops from an initial level of 0.4. Thus, both the tillage types did not differ significantly (P>0.05) in its influence. Soil supplements usually improve soil carbon levels. This was more pronounced in 2014, with P_4 and P_3 amendments in millet cultivation and P_3 amendment in sorghum cultivation producing the best pH levels of 0.54 and 0.53 respectively, which is an increase 16.6% and 15%, respectively. The increase is only 10% and 8%, respectively when compared with P_1. Doumbia et al. (2009) reported 12% increase for ridge tillage, whereas Lashermes et al. (2009) mentioned on the influence of exogenous organic matter like compost to improve soil organic carbon storage.

The influence on total nitrogen, available phosphorus and exchangeable potassium content by the type of tillage employed and soil supplements used

Acidic soils have reduced nitrogen content, which is an important determinant of crop growth, yield and quality. Soil supplements need to improve soil nitrogen levels by 0.13 to 0.23% (Soil Testing Guide, 2013) to have a positive impact.

Inconsistent data were reported regarding the influence of tillage practiced and soil supplements added on nitrogen content of soil. No significant improvement of the low nitrogen levels was reported. The nitrogen levels were so drastically low that they could not even meet the basic needs for the growth of the plant. In fact, such a scenario led to further reduction in the nitrogen content of the soil by nutrient mining. Nutrient mining takes place when the crop cannot meet its nutrient demand by the amendments to soil, and therefore depletes the soil of the native nutrients. Nutrient mining was demonstrated by the initial 50% decline in the nitrogen levels (0.02%) in the control plot (P_0=0.01%) and in the Profeba plot (P_1= 0.01%) under millet cultivation. Vistosh (1995) reported the loss of nitrogen of the soil in the form of nitrates and ammonium because of soil leaching in sandy soils.

For sorghum crops, during the cropping season of 2014, Profeba + urea (P_2) and Profeba + urea + lime (P_4) improved soil nitrogen levels. This is probably because of the high nitrogen content in urea, which is balanced by the profeba compost.

Acidic soils like sandy loam also report low available phosphorus content. Phosphorus is essential for plant respiration, photosynthesis, microbial turnover and decomposition of litter. In cereal crops, sufficient phosphorus levels ensure crop quality and straw strength. Therefore, soil available phosphorus levels need to be improved to 20 mg kg^{-1}(Soil Testing Guide, 2013) for significant improvement in crop growth and yield.

During both the cropping seasons for both the crops, all types of tillage practices reduced the available phosphorus content of soil. However, phosphorus levels were better under ridge tillage in comparison to hoe tillage.

Phosphorus levels improved by 1.0% and 37%, respectively for millet and sorghum crops from the initial level of 2.04 mg kg^{-1} by ridge tillage in the cropping season 2014. Hoe tillage improved phosphorus levels by 24% for sorghum. However, both tillage practices could not significantly ($P>0.05$) influence plant growth. Adding supplements to soil improved phosphorus levels in the 2014 cropping season. Profeba + TPR + Urea (P_3) combination produced the maximum phosphorus levels at 2.47 mg kg^{-1} and 4.01 mg kg^{-1}, respectively for millet and sorghum crops, which is an increase of 17% and 49%, respectively from the initial levels. These values corresponded to 1.9% and 17% increase with profeba alone. On analyzing the interaction between tillage practices and soil supplements for sorghum cultivation in 2014, phosphorus levels improved from the initial value (2.04 mg kg^{-1}) by 40% and 55%, respectively for hoe and ridge tillage. For sorghum during the cropping season of 2014, P_3 x R_1 and P_3 x R_2 amendments improved soil available phosphorus content by 40% and 55%, respectively for hoe and ridge tillage. This improvement was from an initial level of 2.04mg kg^{-1}.

Soil available phosphorus content mainly improved because of the impact of Profeba compost on soil pH. Profeba alone could improve soil pH by 10 and 8%, respectively for millet and sorghum crops. On combining profeba with TPR and Urea, the improvement was up to 13 and 14%, respectively. Kelebonye (2011) also reported similar findings. He noticed improvement in soil pH and phosphorus availability when kraal manure was added and by the liming action.

Potassium levels were also low in acidic soil. Soil potassium levels need to be improved to about 0.20 cmolc kg^{-1} (LSEP, 2008) and 0.45 cmolc kg^{-1} to 0.7 cmolc kg^{-1} (Soil Testing Guide, 2013) for efficient crop cultivation.

Inconsistent data were reported regarding the influence of tillage practiced and soil supplements added on potassium content of soil. No significant improvement of the low potassium levels was reported. The potassium levels were so drastically low that they could not even meet the basic needs for the growth of the plant even on supplementing with profeba. In fact, such a scenario led to further reduction in the potassium content of the soil by nutrient mining.

The reduction in potassium levels could also be because of leaching and rapid potassium uptake by plants. Haque (2007) reported that potassium ions (K^+) are highly soluble, are therefore can be leached easily from soils without colloids. Wang et al. (2013) reported the greater absorption of potassium by plants to attain its maximum yield. No other nutrient is reported to be absorbed in such great levels except nitrogen. Increased rainfall during the cropping season of 2014 (932 mm) than 2013 (720 mm) could also have leached the potassium in the soil. Lehmann (2003) too indicated that increased rainfall leached potassium in sandy soils.

Influence of Type of Tillage Employed and Soil Supplements Used on Grain Yield

The acidic sandy loam soil in the study site had low nutrients. This impacted plant growth and yield. Therefore, the nutrition of such soils needs to be improved by any intervention. For both crops, instead of only using Profeba, its combination with Urea, TPR and Lime produced better results under ridge tillage as well as hoe tillage.

The cropping season of 2014producedbetter grain yield than 2013. This was attributed to the better rainfall in 2014. Several studies have mentioned this relation between grain yield and rainfall for millet and sorghum crops (Krishna, 2004 and Mijinyaw, 2015).

Any supplement added to the soil resulted in improved grain yield. For millet, during the cropping season of 2013, grain yield in comparison to the control improved by 52.9 to 76.5 percentages. The improvement by supplements was in the following order: $P_4>P_2>P_3>P_1$. For millet, during the cropping season of 2014, grain yield in comparison to the control improved by 62.1 to 69.3 percentages. The improvement by supplements was in the following order: $P_3>P_2>P_4>P_1$. For sorghum, in 2013, the grain improved by 72.4 and 85.3 percentages. The supplements influenced crop yield in the following decreasing order: $P_2= P_1>P_4>P_3$. In 2014, improvement was by 90.3 to 92.3 percentages in the order of $P_4>P_2>P_3>P_1$ amendments. Therefore, sorghum had a more positive influence by the soil supplements, which was enhanced with better rainfall. This suggests that sorghum is more responsive to the interventions in comparison to millet. The improved grain yield with soil supplements in comparison to the control in because of increase in nutrients in the soil, which further improved with better rainfall in 2014.

Mineral fertilizers and lime complement the influence of Profeba, and further increase grain yield. This could be because of the greater access to nutrients from the fertilizers. In addition, the minerals fertilizers in the compost enhance its proficiency by mineralization, as reported by Zougmore et al. (2003). These interactions helped in improving the grain yield in both crops.

Ridge tillage improved soil moisture retention and availability, as illustrated by Doumbia et al. (2008). This resulted in significant improvement in crop biomass and grain yield.

Influence of the Tillage Practice and Soil Supplements on Sorghum Value Cost Ratio

Value Cost Ratio (VCR) evaluates the profit in cost because of the combined usage of profeba with urea, TPR or lime by farmers holding small pieces of agricultural land in Mali. Ridge tillage in combination with Profeba + Urea produced the best profits in sorghum, with a VCR of 1.21. However, this best VCR is less than 2, which is on the lower threshold for a profitable operation (Heerink, 2005).

CONCLUSIONS

Final Implications

Profeba by itself has a liming effect, and is capable of increasing pH levels from 4.78 to 5.33, and thereby increasing grain yield. However, its influence can be improved with the addition of mineral fertilizer and lime.

Addition of soil supplements improved crop yield, but its influence was more significant with better rainfall. P_2 and P_3 amendments recorded the highest grain yield. Ridge tillage should be the preferred tillage practice in the Siguidolo area. For both the crops, P2 amendments produced the highest VCR; however, it was less than 2, which in the lowest in the threshold for a profit.

SUGGESTIONS

Additional studies in the study area with different tillage practices and soil supplements would enable producing consistency in the results, and may explain the variations.

Studies are also required to adjustthe fertilizers, so that they are cost-effective and cater to the economic condition of the poor, small-scale farmers.

To improve in-situ moisture storage, methods such as Zai and bunds need to be studied in detail, as rainfall has been shown to significantly influence crop production.

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